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ON IMPROVEMENT OF AIR FLOW IN WIND TUNNELS

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By C. Wieselsberger.

Abstract

The most important aerodynamical qualities that should be aimed at in wind tunnel design, are as follows:

1) Constant and parallel direction of flow;

2) Uniform velocity across all sections;

3) Absence of turbulent motion;

4) Constant velocity of flow.

The above-mentioned qualities are all realized in a high degree in the Göttingen type of wind tunnel, with a parallel portion before the working section, the cross section of which is steadily reduced. It is shown, in what follows, that the system can be easily applied to other wind tunnels, such as the N.P.L. or the Eiffel type. A recently constructed Eiffel tunnel of 1.25 m (4.1 ft.) diameter, the design of which was based on this principle, gave very satisfactory results.

An air stream employed in aerodynamic investigations of aircraft models or of individual parts and auxiliary apparatus

* "Ueber die Verbesserung der Strömung in Windkanalen," address delivered at the 108th session of the Society of Mechanical Engineers, March 19, 1925. From Journal of the Society of Mechanical Engineers (of Japan), Vol. XXVIII, No. 98, June, 1925.

should fulfill the following requirements:

1. Constant and parallel direction of flow with respect to time at all points;

2. Local constant velocity at all points;

3. Freedom from turbulence;

4. Constant velocity with respect to time.

Requirements 1 to 3 depend on the type of wind tunnel construction, while the 4th requirement of constant velocity with respect to time, is clearly dependent on the degree of uniformity of the power operating the fan. Regarding the demand for freedom from turbulence, the objection might perhaps be raised that the turbulence has, in many cases, the same effect as increasing the Reynolds Number.* Thus, in experiments with reduced models in the presence of turbulence, the flow around the model and the flow around the original show a better agreement than in the case of a smooth air stream. Such an effect would be quite desirable. In this connection, however, the following remark should be made. It has not yet been definitely ascertained as to whether, in the case of experiments with models, the turbulence is an advantage under all circumstances and has the same effect as the increasing of the Reynolds Number, since the information on this subject is still in-

*Cf. L. Prandtl, "Der Luftwiderstand von Kugeln," Nachrichten der Königlichen Gesellschaft der Wissenschaft in Göttingen; Math. phys. Klasse 1914, or C. Wieselsberger, Zeitschrift für Flugtechnik und Motorluftschiffahrt, 1914.

sufficient. It is quite conceivable, however, (and this possibility must be taken into account) that, in certain cases, the air stream is affected by the turbulence in quite a different and perhaps undesirable manner.* Besides, we often have to test, in the wind tunnel, full-scale objects, such as radiators, spars, and landing gear parts. In these cases, a turbulent stream would give a wrong idea of the actual relations. A turbulence-free air stream is also necessary for testing and calibrating instruments (for example, air-speed meters). Lastly, it may be remarked that a non-turbulent flow is very easily rendered turbulent to any desired degree by the interposition of a net of wire or thread, if required for certain experiments, while the reverse is not so easily accomplished. We see, therefore, that the preference must unquestionably be given a wind tunnel with as smooth an air flow as possible.

In order to be able to compare different wind tunnels with respect to their degree of turbulence, it is desirable to have some sort of standard. The value of the critical Reynolds Number of a sphere would be a suitable standard for this purpose. In the light of the available results of previous experiments, the higher the critical value of Reynolds Number, the less the turbulence. From this standpoint, it can be shown, by way of

*That the drag curves are drawn together by the effect of the turbulence, not simply at the smaller Reynolds Numbers, is apparent from the results of the investigation of spheres in Figure 7, where both the general course of the four plotted curves and also the absolute values of the drag coefficients of the corresponding sections of the curves differ decidedly.

example, that both the English wind tunnel (N.P.L. type) and the French wind tunnel (Eiffel type) exhibit a higher degree of turbulence than the new Göttingen wind tunnel. Both the former tunnels give, for the critical Reynolds Number of a sphere, a value ranging from 120,000 to 150,000, while measurements in the new Göttingen tunnel give a value of about 240,000. The higher degree of turbulence in the English and French tunnels is mainly due to a honeycomb, which is installed in the tunnel a short distance ahead of the model, in order to render the flow parallel.

In the Göttingen tunnel the honeycomb is in a space having a large cross section. Beginning at the honeycomb, the cross section is gradually reduced downstream to about one-fifth (Fig. 1). The consequence of this is that the vortices produced by the honeycomb have a comparatively long way to travel to the model and are therefore noticeably lessened. By reducing the cross section, a noticeable lessening of the vortices ensues, which cannot be easily explained. The Göttingen type of construction moreover, furnishes a means for obtaining a uniform velocity distribution over the entire cross section. Thus, if the air flow is made parallel by the honeycomb, the dynamic pressure and, consequently, the velocity will still vary from point to point, while the static pressure, on the contrary, will remain constant over the whole cross section. Constant static pressure and variable velocity are compatible with each other throughout.

It reminds one of the laminar flow in a straight tube in which, with constant static pressure over the cross section, the velocity distribution is parabolic; or of the relations in a free air stream, where the stream is surrounded by air at rest, and the static pressure in the flowing air and in the quiet air is, however, the same. If the tunnel cross section is gradually reduced to one-fifth, the velocity will increase fivefold and the dynamic pressure and kinetic energy twenty-fivefold. This increase is produced by the pressure difference $p - p_0$ between the wind tunnel and the surrounding space. From what has been said above, it follows that this pressure difference between all points of a cross section, inside and outside of the stream, is constant. 24/25 of the kinetic energy of the stream comes, therefore, from this constant pressure difference, while the remaining 1/25 was already present in the incoming air. The irregularities of the incoming energy are therefore subsequently included only in this 1/25. If we assume that the incoming local irregularities amount to 50% of the kinetic energy, then the ultimate variation in the free stream will amount to only 2% of the kinetic energy or 1% of the velocity (See Fig. 1, which was drawn for these conditions). It is obvious that, by this comparatively simple method, we can obtain a very uniform velocity distribution over the cross section. As a further noteworthy advantage for the economy of the wind tunnel, it must be added that the losses in the energy of flow, due to the honeycomb, are very small since, in contrast with the English and French types, the honeycomb is located in a section where the kinetic energy is very small.

The Göttingen principle of construction could be applied to the N.P.L. and Eiffel types without difficulty. It is only necessary to replace the hitherto customary exit cone by a different one. The latter (Fig. 2) has a well-rounded inlet, followed by a parallel middle portion which contains the honeycomb, beyond which there is a gradual reduction in the cross section of the tunnel up to the entrance cone and the working section. The difference in comparison with the Göttingen tunnel, consists simply in the absolute value of the pressures p and p_o. In the Göttingen tunnel, atmospheric pressure prevails in the free stream, and positive pressure at the honeycomb. In the modified type of tunnel, atmospheric pressure exists in the experiment chamber, while in the free stream, and also in the experiment chamber, negative pressure prevails. Naturally, the absolute value of the pressure is of no importance for the resulting air flow, since the latter depends only on the pressure difference. Under otherwise like conditions we get the same air flow as long as the pressure difference remains the same.

A wind tunnel of the Eiffel type with 1.25 m (4.1 ft.) air stream diameter and an exit cone of the proposed shape (G. Kenkyujo's wind tunnel) demonstrated, in an aerodynamic test, that the good qualities referred to above, were actually present. Measurements of the velocity distribution, made on three vertical sections, 0.0, 0.60 m (1.97 ft.) and 1.25 m (4.1 ft.) distant, respectively, from the rim of the entrance cone (Figs. 3 to 5), showed that the velocity variations from the mean value were not more than ±0.5%. Probably they are really even smaller, since the accuracy of these measurements was impaired by the circumstance that the air velocity, due to variations in the speed of the motor, showed strong fluctuations with respect to time. Two Pitot tubes were therefore employed, one of which was moved along a cross section while the other one was stationary. Both instruments were read simultaneously, and the reading of the movable tube was subsequently converted to the constant value of the fixed tube. It was found that an exactly simultaneous reading is very difficult, even when two observers work well together, and errors of ±0.5% inevitably occur. It is quite possible, therefore, that the distribution is really better than that shown by the experimental results. A series of velocity measurements along the tunnel axis (Fig. 6) shows that, even in the axial direction, the velocity is practically constant.

In order to determine the degree of turbulence of the air stream, the resistance or drag of an aluminum sphere of 20 cm (7.87 in.) diameter was measured in relation to the Reynolds

Number, and the drag coefficient k_d* relative to the Reynolds Number R was computed. The result is diagrammatically represented by Figure 7. The critical Reynolds Number is about 300,000, a value thus far obtained in no other wind tunnel. As regards the measurement itself, it may be remarked that the sphere was fastened to the forward end of a horizontal bar, and that all the suspension and measuring wires were attached to this bar, so that the sphere itself was entirely free from wires.

A very favorable value was also obtained for the efficiency of the tunnel. The performance measurements indicated that, with an effective motor output of $P_e = 40.5$ HP., a dynamic pressure of $q = 101$ kg/m² (20.7 lb./sq.ft.) was obtained, which, at the prevailing atmospheric density, corresponded to an air speed of 39.9 m/s (130.9 ft./sec.). For a cross section of $f = 1.294$ m² (14 sq.ft.) the air power is therefore

$$P_1 = \frac{q\ v\ f}{75} = 69.7 \text{ HP.}$$

If we let $P_e = k\ P_1$, the coefficient k** is then a measure of the wind tunnel efficiency, including the fan. The efficacy of the available motor power is inversely proportional

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* The drag coefficient k_d is defined by the formula: Drag $W = k_d\ Fq$, in which F = area of the main transverse section and q = dynamic pressure.

** $k = \dfrac{1}{\text{Energy ratio of N.A.C.A.}}$, wherein output power is used instead of input power.

to the value of k. In our case, k is found to be 0.58. For the Göttingen and Eiffel tunnels the values are respectively, 0.68* and 0.73**.

The flow direction at different points was first tested qualitatively with fine silk threads. Good parallelism of the air stream was found at all points, and even the directional variations with respect to time were very small.

Translation by
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for Aeronautics.

* Cf. L. Prandtl, "Ergebnisse der Aerodynamischen Versuchsanstalt" at Göttingen, Report I, p. 19.

** G. Eiffel, "Nouvelles recherches sur la resistance de l'air et l'aviation," second edition, p. 6.

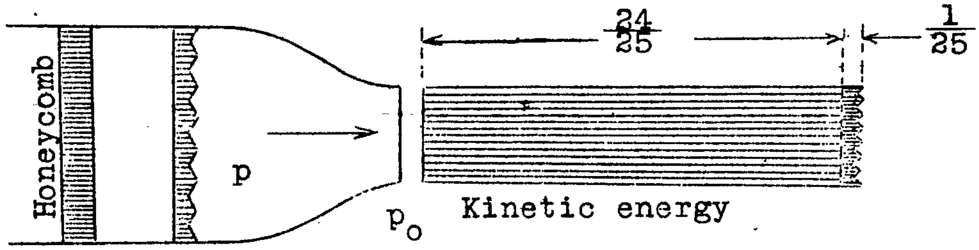

Fig.1

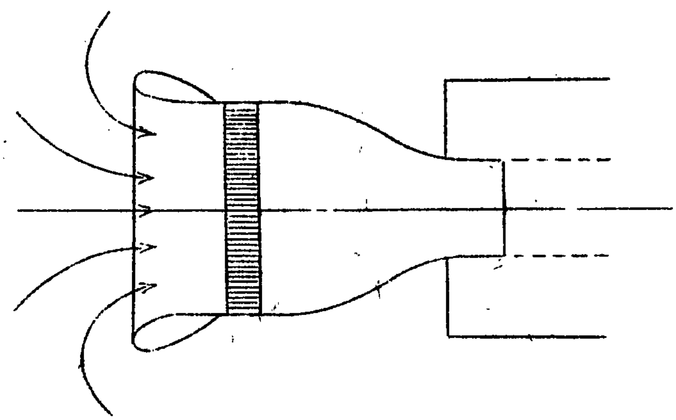

Fig.2

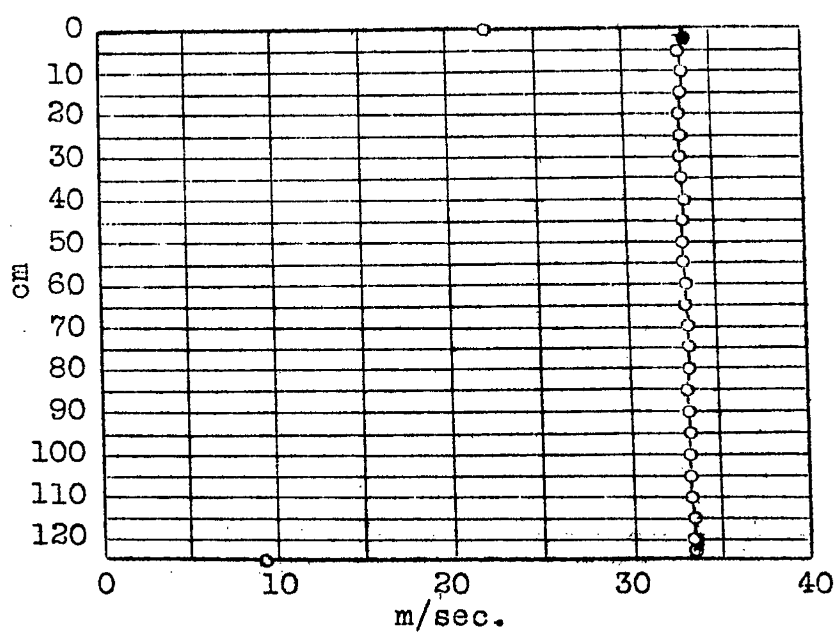

Fig.3 With d = 0 cm

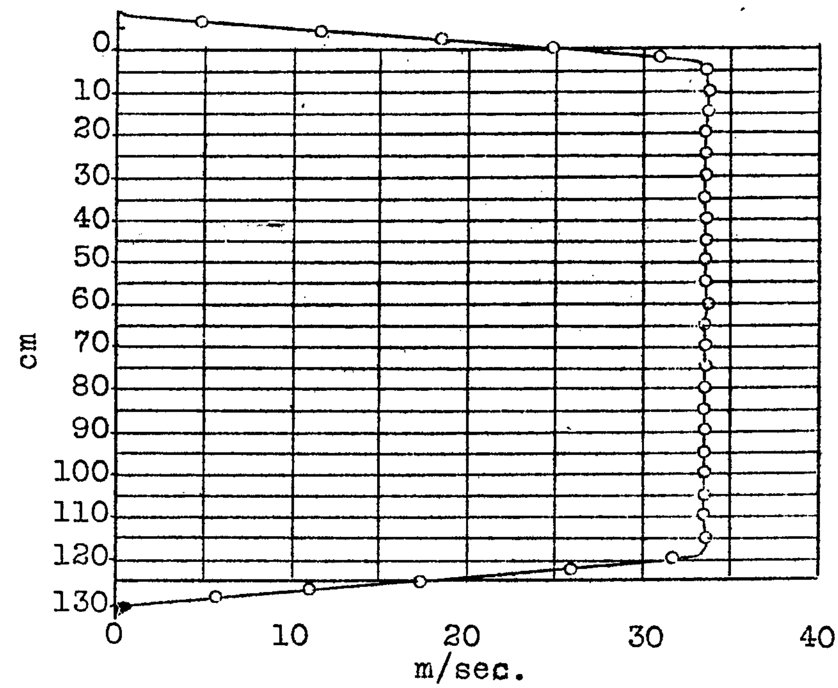

Fig.4 With d = 60 cm

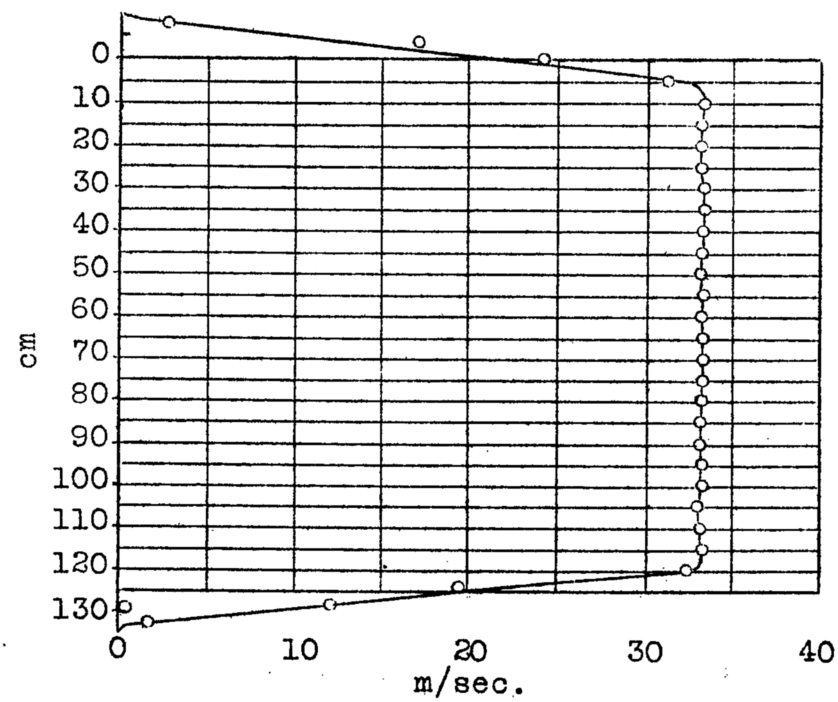

Fig.5 With d = 125 cm

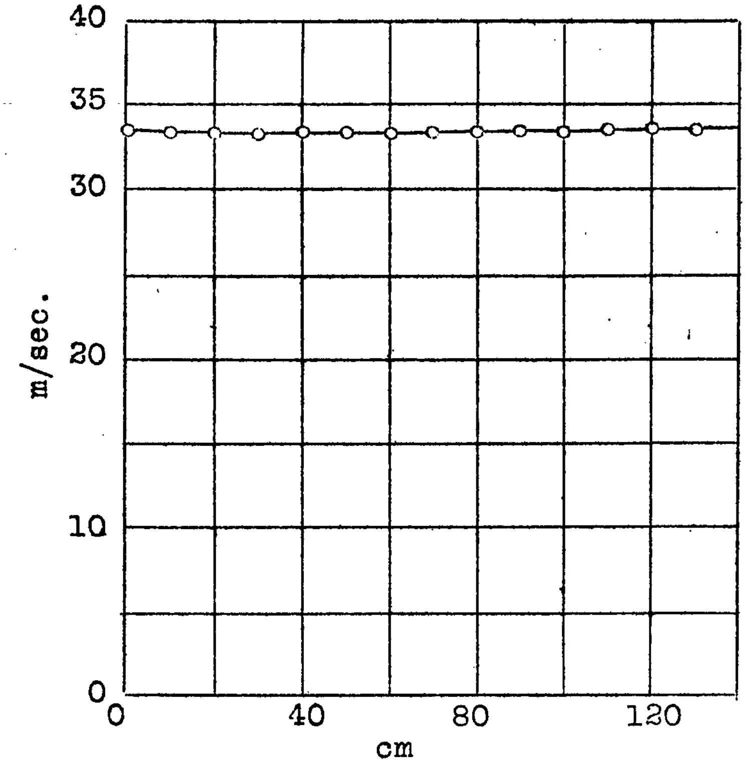

Fig.6 Axil distance from funnel.

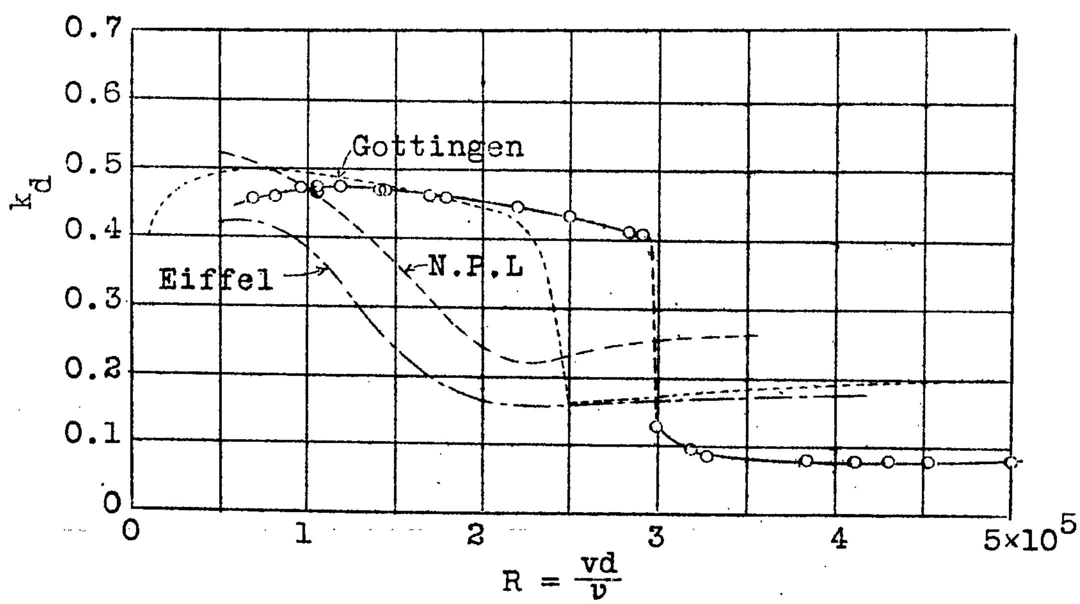

Fig.7

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